Development, Calibration, and Analysis of a Hydrologic and Water-Quality Model of the Delaware Inland Bays Watershed

Progress Report January 1– June 30, 2001

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Progress Report: January 1–June 30, 2001

Personnel

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Project Description

Problem
The Delaware Inland Bays have experienced significant environmental degradation due to human activities over the past several decades. Excessive nutrients and sediment are among the most severe environmental stressors in the Inland Bays. The sources of nutrients, sediment, and other contaminants include point-source discharges from industries and wastewater-treatment plants, runoff and infiltration to ground water from agricultural fields and poultry operations, septic-system effluent, and atmospheric deposition.

In order to determine how best to approach restoration of the Inland Bays, it is necessary to understand the relative distribution and contribution of each of the potential sources of nutrients, sediment, and other contaminants. It is also important to understand the hydrology of the Inland Bays Watershed in order to effectively restore them. Understanding the complex interrelations and interactions between hydrology and the various water-quality inputs is a prerequisite to restoration.

Objective
This project is a cooperative effort involving the Delaware Department of Natural Resources and Environmental Control (DNREC), the Delaware Geological Survey (DGS), and the U.S. Geological Survey (USGS). The objective of this project is to develop a hydrologic and water-quality model of the Delaware Inland Bays Watershed that can be used as a water-resources planning and management tool. The water-quality constituents of concern will be suspended sediment and nutrients (nitrogen and phosphorus). A well-documented model, Hydrologic Simulation Program—FORTRAN (HSPF), will be applied by the USGS to meet the objective.

The USGS role in this cooperative project is to construct, calibrate, and demonstrate the use of the hydrologic and water-quality model for the portion of the Inland Bays Watershed discharging to the Bays themselves. The following tasks are included in this role: (1) Compilation of existing hydrologic, climatological, water-quality, and ancillary data into model data sets; (2) construction and calibration of a hydrologic model; (3) construction and calibration of a water-quality model for suspended sediment, nitrogen, and phosphorus; (4) use of the model to simulate selected scenarios of the allocation of point and nonpoint sources; and (5) presentation of the model results to DNREC and DGS in the form of electronic model files, a written USGS report, and training in use of the model.

Background
The hydrologic and water-quality data needed to calibrate the model were collected during Federal Fiscal Year 1999 and the beginning of Federal Fiscal Year 2000. The USGS collected streamflow data at six stations in the Delaware Inland Bays Watershed, and the University of Delaware and DGS collected water-quality data at the same six stations for the same time period. All the streams for which data were collected (except Munchy Branch, 01484668) are on Delaware's 303(d) list, and all six

streams also were monitored as part of Delaware's water-quality monitoring program in Federal Fiscal Years 1999 and 2000.

Responsibilities

USGS is responsible for developing the HSPF model framework and for model calibration. The framework of the model is based on Geographic-Information-System (GIS) data in ARC/INFO format previously prepared by USGS for DGS, and supplemented by DNREC and other agencies as appropriate. GIS data include land use, geology, soils, digital-elevation-model (DEM) data, drainage basins, stream network, data-collection points, and point-source discharges. The data sets will be properly attributed and include critical information such as fertilizer application rates and timing for agricultural areas and lawns. USGS will use the GIS data to build the framework of the model and produce appropriate model segmentation. USGS will provide streamflow data and assemble climatological data for model operation.

DNREC is responsible for providing existing water-quality data including suspended-sediment, nitrogen, and phosphorus concentrations for calibration points and other model nodes of interest. These data will include all the water-quality data collected by the University of Delaware and DGS during 1999 and 2000 at the six established stream stations mentioned above, as well as any other pertinent water-quality data for the Inland Bays Watershed. DNREC will also provide quantity and quality data for point-source discharges to streams in the study area, and supply or facilitate the obtaining of other data needed for the model application, including stream hydraulic characteristics and fertilizer-application data.

DGS is responsible for supplying selected data that may enhance the model application, including analysis and interpretation of results. DGS provides coordination between USGS and DNREC as appropriate.

Progress

During the past six months the following tasks were completed: (1) development of the model segmentation; (2) allocation of land use data by model segment; (3) measurement of stream cross-sections throughout the basin; (4) collection and quality control of meteorological data; (5) definition of hydrologic parameters based on soil information; and (6) sensitivity analysis and calibration of the hydrologic model at locations with continuous discharge data.

Because of the composition of the monitored data as "total suspended solids" (which includes mineral and organic matter), it was decided to perform the calibration for sediment parallel to the calibration for nutrients rather than prior to the calibration for nutrients.

Model Segmentation

Model segments were developed based on preliminary watershed boundaries for Sussex County provided by John Mackenzie's group at the University of Delaware (http://bluehen.ags.udel.edu/spatlab/basins/). The location of point sources and stream gages, the terrain and the location of impairments served as the main criteria to developed the final model segmentation. The delineation was based on 30-m Digital Elevation Model (DEM) or 1:24,000 topographic maps, and the external basin boundary was provided by DNREC. Model segments ranged between 2.2 and 20.5 mi^2 in size.

Stream elevation was calculated from 1:24,000 topographic maps, while the stream length was obtained from the length attribute in the National Hydrography Dataset (NHD) coverage.

Land Use
Land use data was obtained from DNREC and allocated by model segment as shown in Figure 1. The model includes the simulation of nine pervious and two impervious land uses. The final aggregation is contained in Table 1.

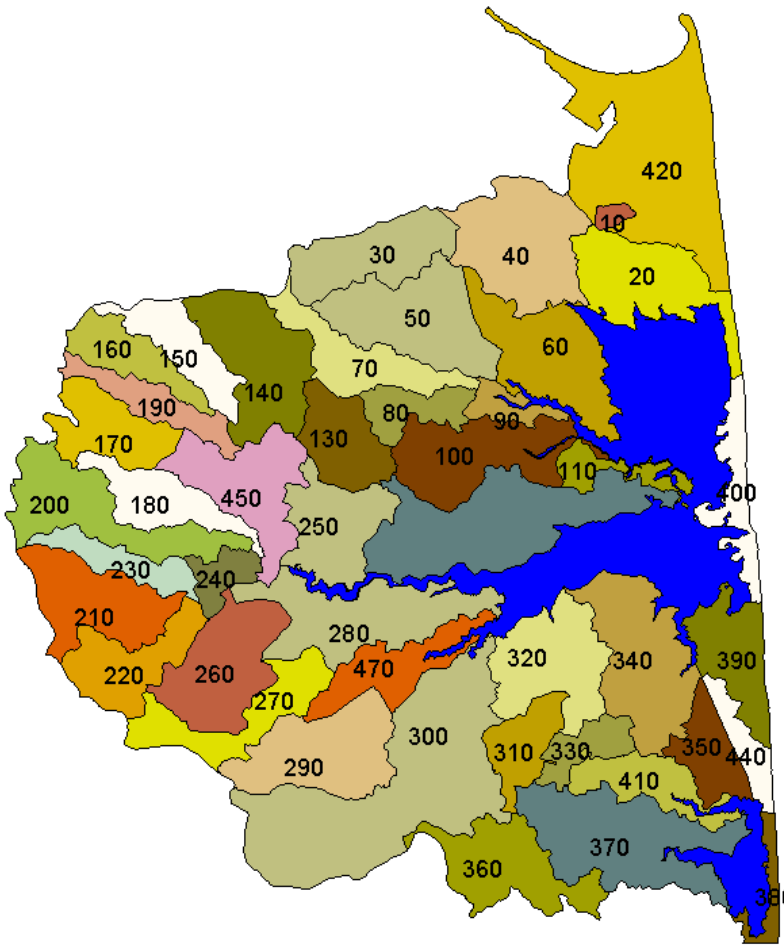

Figure 1. Inland Bays HSPF model segmentation.

Stream Cross-sections
For the calibration of the model hydrology and in order to define functional relationships between variables such as depth, surface area, and volumes, stream cross-sections were measured at the outlet of the following HSPF model segments: 50, 140, 150, 160, 190, 200, 210, 220, and 260 (Figures 2-9).

SEG	WATER	FOREST	WETLAND	BARREN	BRUSH	CROPS	ORCHAD	PASTURE	LOW_R	MID_RES	HIGH_RES	INSTIT	INDUS	COMM	TOTAL
10	0.0	14.9	10.8	0.0	0.0	86.4	0.0	0.0	113.8	0.0	26.2	0.0	10.5	66.3	328.9
20	228.8	410.8	761.9	110.3	85.4	786.7	0.0	0.0	1560.7	0.0	540.4	19.6	100.4	177.7	4782.7
30	0.4	1515.9	206.3	9.5	18.2	1926.4	0.0	18.0	269.8	16.1	0.0	0.0	19.9	0.0	4000.5
40	152.0	1524.2	511.1	117.2	2.3	2707.4	0.0	80.8	728.5	9.6	124.1	0.0	0.0	11.9	5969.1
50	2.0	2248.4	383.1	13.9	222.7	1979.2	0.0	0.0	623.3	5.8	0.0	0.0	37.2	0.0	5515.6
60	144.3	1517.3	1019.5	220.2	12.9	1142.7	0.0	19.0	771.3	0.0	372.5	0.0	0.0	0.0	5219.7
70	0.0	979.4	181.4	3.6	107.3	1804.6	0.0	13.7	136.0	5.1	69.6	0.0	22.4	0.0	3323.1
80	0.6	626.4	91.4	40.3	23.1	898.7	0.0	0.0	86.6	0.0	54.3	0.0	8.8	0.0	1830.2
90	16.6	316.7	75.9	6.6	1.5	272.5	0.0	0.0	294.5	0.0	36.6	0.0	0.0	0.0	1020.9
100	76.8	1353.5	280.0	402.5	282.8	1454.6	0.0	35.7	505.7	8.1	333.9	0.0	49.4	52.8	4835.8
110	96.4	150.3	472.6	50.5	31.6	164.3	0.0	22.8	18.4	0.0	316.3	0.0	0.0	12.8	1336.0
120	296.7	1963.1	838.3	146.4	102.2	2272.6	0.0	42.5	1027.7	21.2	1324.3	0.0	23.9	98.1	8157.0
130	1.8	1737.0	37.7	5.2	232.0	632.6	0.0	0.0	145.4	4.7	84.8	0.0	11.9	0.0	2893.1
140	33.4	2465.9	605.8	25.9	105.5	1414.3	0.0	13.8	456.1	42.7	12.8	0.0	26.3	1.5	5204.0
150	4.2	1038.1	178.6	15.9	87.6	515.3	17.2	0.0	303.8	9.4	32.0	0.0	478.1	8.0	2688.2
160	13.3	486.5	419.7	69.2	119.7	721.1	0.0	27.1	418.7	26.1	50.6	28.2	41.0	62.5	2483.7
170	38.4	382.0	588.2	48.4	1.2	1540.6	0.0	0.0	305.2	50.2	0.0	4.0	80.0	77.8	3116.0
180	43.0	923.4	168.0	17.2	22.6	1331.8	0.0	6.8	275.5	35.9	57.7	6.0	31.1	0.0	2919.0
190	37.8	218.8	161.6	3.1	4.1	1237.0	0.0	0.0	287.3	18.7	37.2	81.7	15.6	60.8	2163.7
200	9.7	1214.0	1013.9	46.2	68.3	2390.7	0.0	12.7	166.4	81.6	20.3	0.0	8.3	0.0	5032.1
210	61.7	2121.4	388.8	22.4	62.2	1466.8	0.0	0.0	183.4	52.3	39.3	0.0	16.6	0.0	4414.9
220	7.0	956.6	688.1	29.9	99.8	1348.6	0.0	1.7	204.6	39.4	55.9	0.0	14.6	0.0	3446.2
230	28.1	594.6	64.0	15.8	13.6	1049.2	0.0	0.0	77.7	38.2	39.2	0.0	0.0	0.0	1920.4
240	105.1	125.2	67.3	29.5	65.5	515.1	0.0	0.0	210.5	25.6	77.5	0.0	21.0	0.0	1242.3
250	77.3	852.3	169.8	15.6	131.9	2218.1	0.0	0.0	84.0	21.1	65.5	0.0	136.1	0.0	3771.7
260	29.9	631.1	1064.2	28.6	139.2	2608.5	0.0	7.8	251.4	68.5	25.4	0.0	33.6	25.7	4913.9
270	1.7	194.2	1206.2	0.0	16.3	1964.0	0.0	0.0	68.6	35.7	68.5	0.0	38.8	0.0	3594.0
280	113.3	1461.8	1068.1	278.5	72.9	1213.9	0.0	18.4	491.2	86.2	408.0	14.0	315.2	140.9	5682.4
290	3.9	369.7	1522.6	8.8	62.7	2613.5	0.0	38.5	152.6	94.6	211.4	26.7	39.0	14.3	5158.3
300	91.6	1891.9	4655.0	158.3	30.0	5055.1	0.0	13.6	589.0	220.5	289.6	12.6	81.2	10.9	13099.3
310	9.0	325.6	181.2	1.6	16.9	1474.8	0.0	6.1	130.1	78.2	5.4	0.0	0.0	0.0	2228.9
320	82.6	1364.4	592.2	83.9	44.5	1468.6	0.0	72.5	824.5	177.2	162.0	0.0	0.0	0.2	4872.6
330	11.5	96.5	106.1	37.6	0.0	1104.8	0.0	7.1	156.4	65.8	1.9	0.0	1.9	0.0	1589.6
340	107.8	1117.9	872.9	106.6	38.7	1802.4	0.0	27.2	1451.9	70.2	244.4	0.0	0.0	111.5	5951.5
350	79.7	238.8	681.9	70.7	13.2	620.2	0.0	0.0	366.8	8.1	123.8	0.0	37.9	14.4	2255.5
360	24.2	345.9	725.0	80.9	63.9	2632.7	0.0	41.7	251.1	140.2	74.2	0.0	0.0	0.0	4379.8
370	385.4	1033.0	1638.4	78.3	25.6	2849.1	0.0	66.1	555.0	154.0	261.6	0.0	0.0	12.8	7059.3
380	121.1	9.6	237.6	159.6	0.0	20.7	0.0	0.0	157.4	0.0	52.0	0.0	38.4	74.5	870.9
390	272.7	291.5	650.4	119.8	158.6	352.0	0.0	0.0	897.8	10.8	261.6	44.0	91.3	72.5	3223.0
400	291.4	56.1	1141.4	363.2	119.5	0.0	0.0	0.0	120.6	0.0	24.2	0.0	114.0	7.1	2237.5
410	80.8	602.1	805.8	11.4	38.6	639.8	0.0	26.8	182.6	66.6	179.7	0.0	3.6	0.0	2637.8
420	587.7	1553.7	2785.7	875.1	300.8	1711.2	0.0	52.1	2101.9	0.0	421.6	226.1	184.1	396.5	11196.5
440	144.9	78.8	111.6	60.7	11.2	0.6	0.0	16.3	744.2	0.0	170.5	0.0	33.6	27.7	1400.1
450	102.3	1537.1	297.5	0.0	205.5	1719.6	0.0	0.0	236.7	60.9	223.4	143.0	12.8	1.1	4539.9
470	46.6	426.9	331.5	78.5	3.8	1351.4	0.0	25.7	349.4	102.5	207.0	9.7	63.0	17.2	3013.2

Table 1. Land use acreage by watershed model segment.

Meteorological Data

Time series were developed using daily precipitation obtained from the National Climatic Data Center (NCDC) for the closest station, and from information collected by the USGS at the stream gages within the basin. Quality control methods were applied to the USGS data, which was the preferred information for the calibration. Air temperature, wind speed, cloud cover, radiation and pan evaporation data were obtained from time series developed by the Chesapeake Bay Program Office for the region.

Hydrologic Calibration
The calibration was performed using the HSPEXP (Expert System) software developed by the USGS. Time series of stream flow were also developed from hourly records and used for the calibration.

Report Planning
A report-planning Meeting was held in the Baltimore offices of the MD-DE-DC District on June 29, 2001. As a result of that meeting, a draft outline, including lists of figures and tables, was prepared (Appendix 1).

Plans for Next Six Months

1. Complete acquisition of data (Table 2). USGS is exploring alternative sources for certain data, such as agricultural data (animal counts, fertilizer applications rates). DNREC will make final recommendations regarding alternative data sources.

2. Define agricultural land use: crop and tillage distribution by model segment.

3. Develop time series for point sources.

4. Develop the following information related to non-point sources and agricultural practices:

    a. Animal Count

    b. Manure Acres

    c. Nutrient Applications (schedule of nutrient applications and recommended applications)

5. Acquire atmospheric deposition time series.

6. Develop septic information.

7. Format water quality data for calibration.

Data Type	Source	Provider	Comments	Comments 2
GIS to define hydrologic response units				***COMPLETED***
Geology	**DGS**	**DGS**		
Soils	**NRCS**	**DGS**		
Land-surface elevation (DEM)	**USGS**	**DNREC**		
Land use and land cover	**DNREC**	**DNREC**	**DE DOP, 1997**	
Natural drainage network (hydrography)	**USGS**	**USGS**	**1:100,000 NHD**	
Artificial drainage network (ditches)	**USGS**	**USGS**	**1:100,000 NHD**	
Drainage basin delineations	USGS/DGS	USGS/DGS	Originally due October 2000	
Input time-series data for hydrologic modeling				***COMPLETED***
Streamflow	USGS	USGS	March 2001	
Meteorological data (precipitation, etc.)	NCDC	USGS	March 2001	
Water use	USGS	USGS	March 2001	
Ancillary data for hydrologic modeling				***COMPLETED***
Channel geometry, roughness, gradient	FEMA	DNREC/USGS	March 2001	
Discrete-sample data for water-quality modeling				
Nutrient concentrations	DNREC	DNREC	April 2001	
Sediment concentrations (total suspended solids)	DNREC	DNREC	April 2001	
Sediment size distribution	DNREC	DNREC	April 2001	
Field parameters (water temperature, pH, D.O.)	DNREC	DNREC	April 2001	
GIS and ancillary data for water-quality modeling				
Cropland	DNREC	DNREC	April 2001	
Pasture	DNREC	DNREC	April 2001	
Confined-feeding operations	DGS	DGS	April 2001	
Fertilizer application rates	USDA	DNREC	April 2001	
Manure application rates	USDA	DNREC	April 2001	
Atmospheric deposition	NADP	DNREC	April 2001	
Wetlands	DNREC	DNREC	Originally due October 2000	
Point sources	**DNREC**	**DNREC**	**NPDES**	

Table 2. Data Requirements and Responsibilities for HSPF Implementation. [DGS, Delaware Geological Survey; NRCS, Natural Resources Conservation Service; USGS, U.S. Geological Survey; DNREC, Delaware Department of Natural Resources and Environmental Control; USEPA, U.S. Environmental Protection Agency; NCDC, National Climatic Data Center; FEMA, Federal Emergency Management Agency; DE DOP, Delaware Department of Planning]

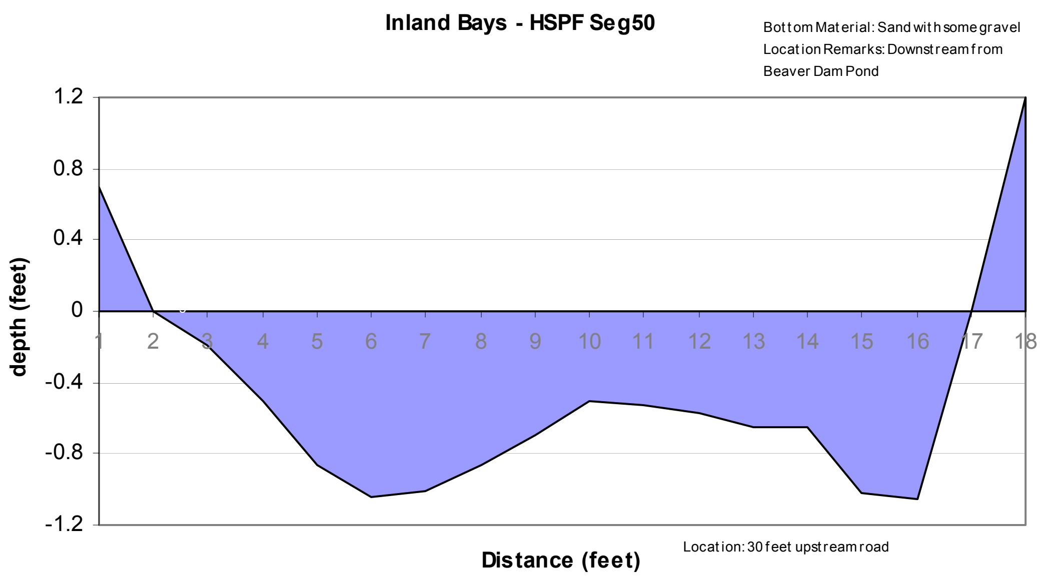

Figure 2. Cross section for stream draining watershed model segment 50.

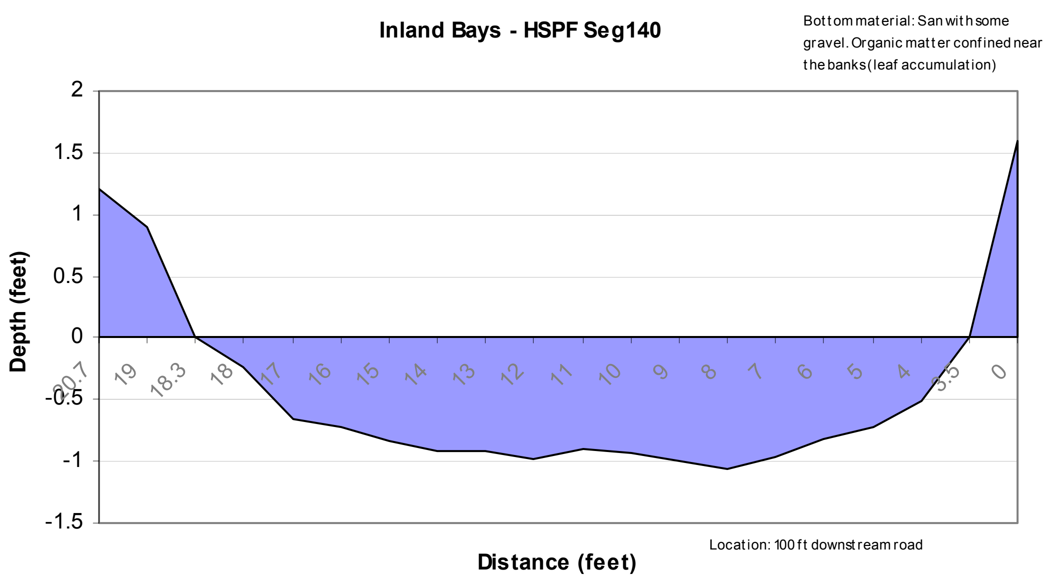

Figure 3. Cross section for stream draining watershed model segment 140.

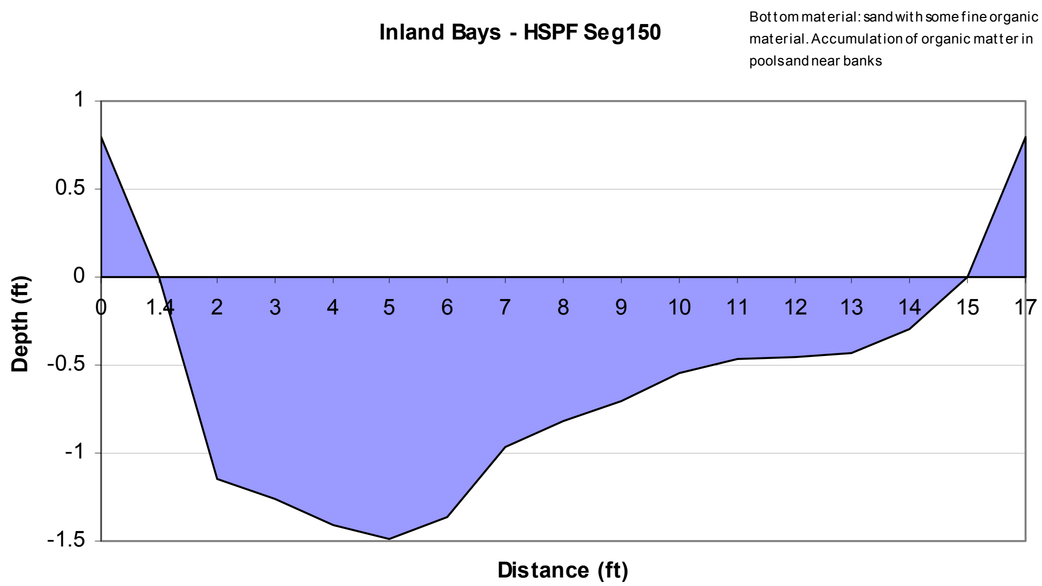

Figure 4. Cross section for stream draining watershed model segment 150.

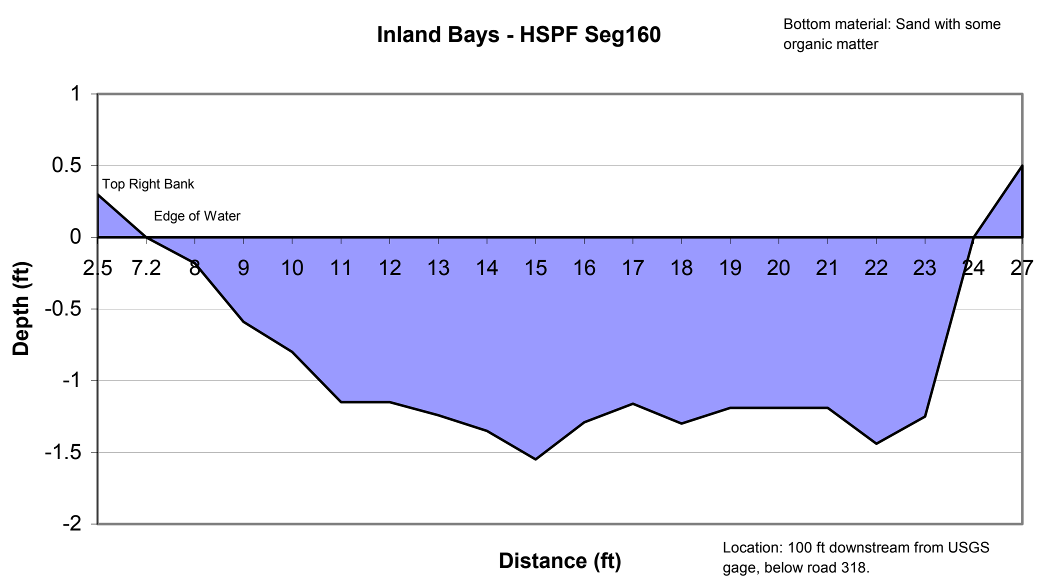

Figure 5. Cross section for stream draining watershed model segment 160.

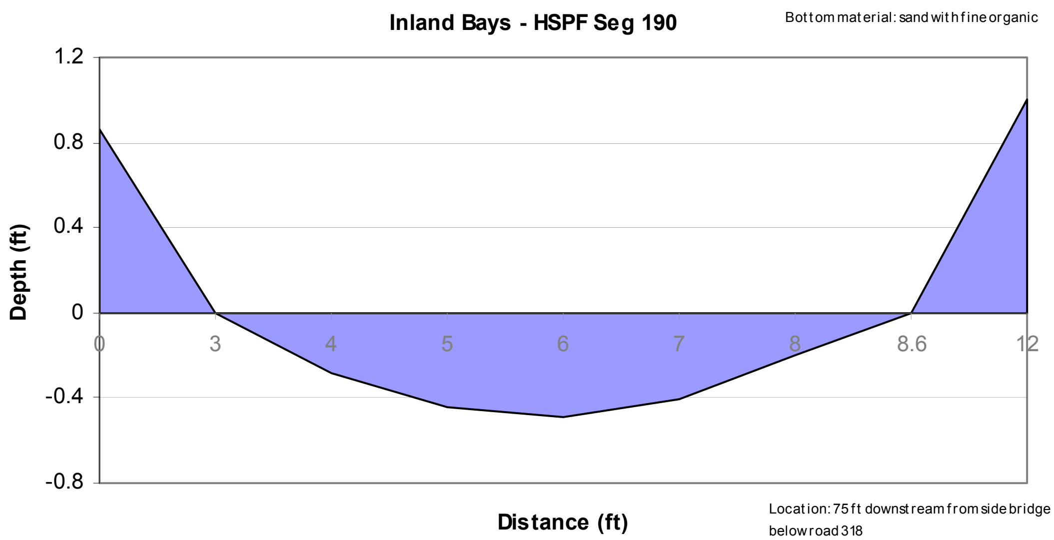

Figure 6. Cross section for stream draining watershed model segment 190.

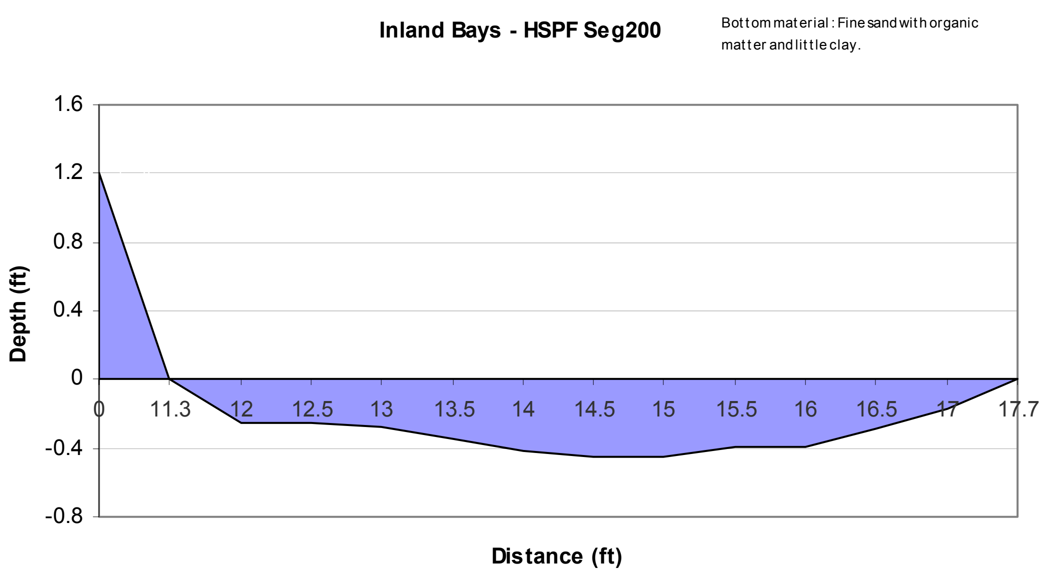

Figure 7. Cross section for stream draining watershed model segment 200.

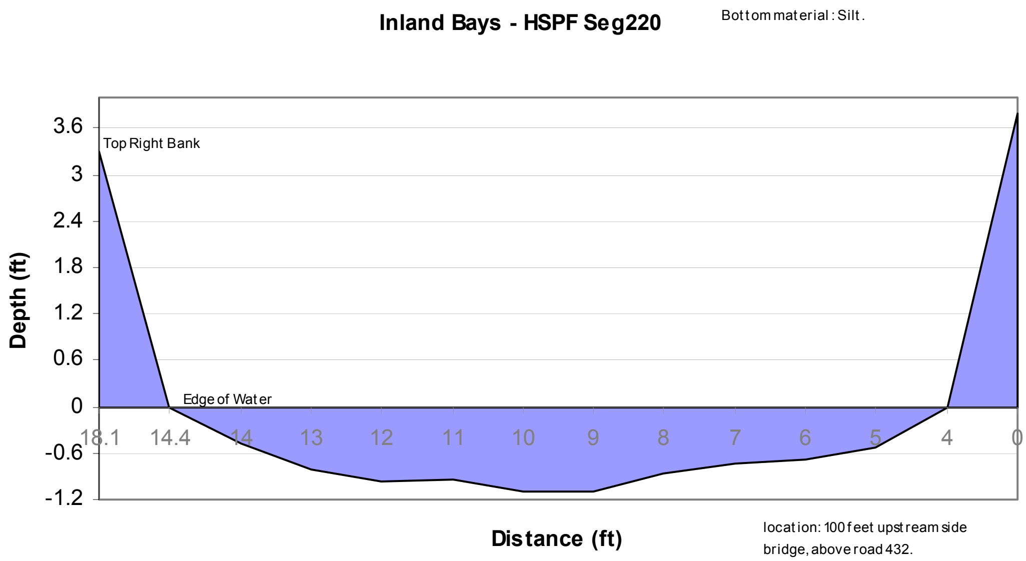

Figure 8. Cross section for stream draining watershed model segment 220.

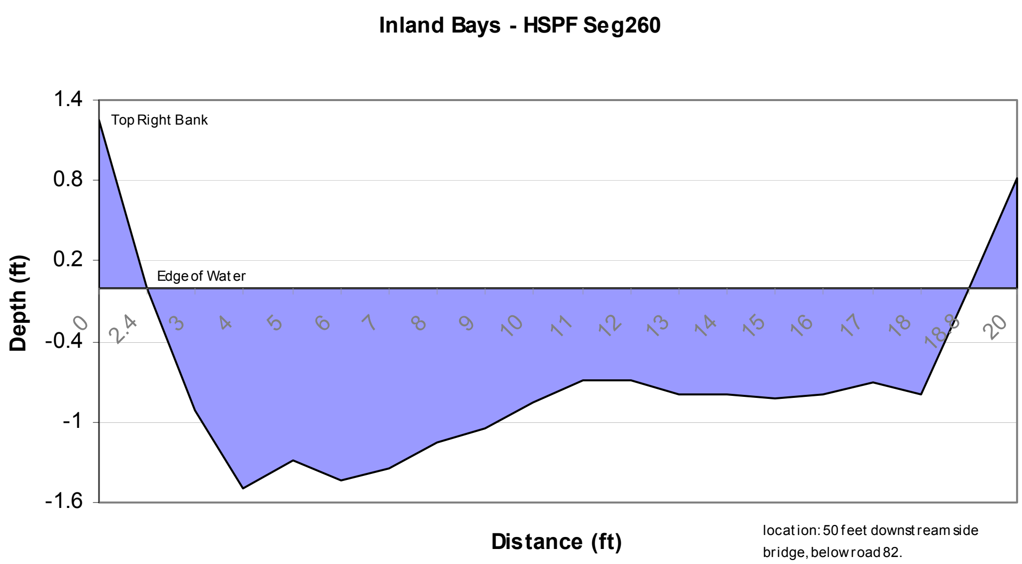

Figure 9. Cross section for stream draining watershed model segment 260.

Appendix 1 Delaware Inland Bays Model Report Planning Package

A report-planning Meeting was held in the Baltimore offices of the MD-DE-DC District on June 29, 2001. As a result of that meeting, a draft outline, including lists of figures and tables, was prepared and is attached.

DEVELOPMENT, CALIBRATION, AND ANALYSIS OF A HYDROLOGIC AND WATER-QUALITY MODEL OF THE DELAWARE INLAND BAYS WATERSHED

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Purpose and Scope (Draft)

This report describes the development, calibration, and analysis of a watershed model for the Delaware Inland Bays Watershed, a cooperative study conducted by the Delaware Geological Survey (DGS), the Delaware Department of Natural Resources and Environmental Control (DNREC), and the United States Geological Survey (USGS). The model was developed using the Hydrologic Simulation Program-FORTRAN (HSPF), and simulates the runoff of water and transport of suspended sediment and nutrients (nitrogen and phosphorus) within the Delaware Inland Bays Watershed. The model provides a comprehensive understanding of the current and potential natural resource management-related impacts in the Inland Bays Watershed.

HSPF is a deterministic lumped-parameter time series model that evolved out of the Stanford Watershed Model (Crawford and Linsley, 1966) and the USEPA Agricultural Runoff Management, or ARM (Donigian and Davis, 1978), and Nonpoint Source, or NPS (Donigian and Crawford, 1979), models. The model uses input information including land use/cover, source (of N and P) data, stream reach characteristics, and time series of precipitation and potential evapotranspiration. A number of simplifying assumptions were made, including the assumption of homogeneity in user-adjustable parameters across the watershed. Time series (observational) data, such as streamflow and water-quality, were used to calibrate the model for water years 1998 through 2000 at six sites within the watershed. The report describes the calibration of the model, and provides statistics on the quality of the calibration. Modeled loads the Bays themselves are reported, based on the calibrated model.